PREFACE

The portion of the Handbook contained herein presents criteria, methods, and equipment for making geologic investigations of damsites and taking samples for laboratory analyses. It is for the use of geologists and engineers in the Soil Conservation Service.

Numerous individuals, both geologists and engineers, have contributed generously to the preparation of this section of the Handbook. Their contributions are herewith gratefully acknowledged.

Washington, D. C. 1961

Reprinted with minor revisions and corrections, May, 1978.

NATIONAL ENGINEERING HANDBOOK

SECTION 8

ENGINEERING GEOLOGY

Safety and Precautions

All safety practices and procedures currently established by safety handbooks and guides of the Soil Conservation Service must be adhered to in field operations.

Emphasis on safety measures as regards drill crews should be placed on the use of safety helmets and other protective devices such as gloves and hard-toed shoes. Personnel operating drill rigs or other persons whose duties require close proximity to machinery in operation or transit, should rid themselves of ragged or torn clothing. Machinery in operation should be equipped with guards on any moving parts insofar as practicable.

Equipment operators should not run the equipment in excess of the limits of capability and safety as established and designated by the manufacturer.

Equipment should not be presumed to be in safe operating condition unless it has been adequately checked by a competent, responsible person.

Regular condition checks should be made on all equipment and the results reported.

Caution must be used when operating equipment in the vicinity of power transmission lines. Consideration should be given to the possible presence of underground utility lines.

Wire ropes or cables used with truck winches frequently are broken. Drilling party personnel should stay well clear of the reach of the cable during operations of the winch.

Crews using geophysical instruments or making other investigations involving explosive charges should be well acquainted with the precautions necessary to avoid accidents. Only properly licensed blasters may handle, load and fire explosive charges. Until such time as this method of exploration is approved for full SCS use, and SCS regulations issued, it is recommended that locally employed, licensed blasters be used.

Where trench or pit excavations require side supports of cribbing, determine that the material for the cribbing is of adequate strength and is so installed that slumping, caving and sliding cannot occur.

Test holes should be covered each evening and plugged level with the surface upon completion of exploration, to prevent accidents. An open hole is a potential danger to humans and livestock; it could cause a broken leg or even more serious accidents. Test pits and trenches should be leveled also upon completion of site investigations.

Caution should be exercised in the handling of radioactive materials and caustic, toxic, or flammable chemicals; for example, the nitrobenzene used in clay mineral tests is poisonous not only if taken internally, but also by absorption through the skin or by inhalation of the vapor.

Avoid personal accidents! Be sure to make reports on accidents within 24 hours. (See Administrative Procedures Handbook.) Get medical assistance if required, even if it is necessary to shut down operations.

All crews should have copies of the First Aid Guide and should have first aid kits as prescribed in the Guide. Snakebite kits are required in poisonous snake-infested areas.

Caution should be exercised when moving drilling equipment on roads, streets, and highways.

Bran or other grain derivatives never should be added to drilling mud since this mixture is detrimental to livestock.

Dye tracers to be used in ground water must be nontoxic to both humans and livestock. Determination of this factor must be made prior to use.

NATIONAL ENGINEERING HANDBOOK

SECTION 8

ENGINEERING GEOLOGY

CHAPTER 1 - DESCRIPTION OF MATERIALS

INTRODUCTION

General

The adequacy of a geologic investigation of a structure site depends upon accuracy in the description and classification of materials at the site and proper interpretation in respect to engineering requirements. Materials at a particular site are to be described and classified according to their geologic and physical properties and their engineering or behavior properties. These are necessary to establish correlation and stratigraphy of the site and to develop the design of the structure and construction methods to fit the particular site condition. This chapter outlines some of the more important properties of soil and rock materials which need to be considered in describing and classifying such materials.

Two systems of describing materials are employed in the engineering phases of damsite investigations: a geologic system, and the Unified Soil Classification System. The geologist must be familiar with both systems. The geologic system is based on the geologic and physical properties of materials. The Unified Soil Classification System is based on a combination of physical and behavior properties. To some extent the two systems overlap and descriptions developed for geologic interpretations also are used for engineering interpretations.

The successful engineering geologist must have a working knowledge of engineering design and construction methods in order to adequately describe and classify materials for engineering purposes. He must understand the terminology used by engineers and be able to present his interpretation in terms readily understood by them. It must be remembered that investigations of damsites are made to obtain information specifically for engineering purposes. Therefore, the terminology used in this handbook departs somewhat from standard terms normally found in geologic texts. The following is a list of some of the more important terms and their meanings as used in this handbook to describe materials:

Rock - A compact, semi-hard to hard, semi-indurated to indurated, consolidated mass of natural materials composed of a single mineral or combination of minerals.

Soils - Unconsolidated, unindurated, or slightly indurated, loosely compacted products of disintegration and decomposition.

Grain - A rock or mineral particle.

Gradation - Relative size distribution of particles.

Well graded - No sizes lacking or no excess of any size range, poorly sorted.

Poorly graded - Skip grades or excess of certain size ranges, may be well sorted.

Silt and Clay - Particles smaller than No. 200 mesh, identified by behavior characteristics rather than specific grain sizes.

Physical and Mineralogical Characteristics of Materials

Particle Characteristics

Particle characteristics, including size, shape, mineral composition, and hardness, are important considerations in establishing the origin of materials and geologic processes involved; and for determining the stratigraphy of the site. Lithologic similarity is one of the bases for establishing correlation and continuity of strata and equivalency in age. Particle characteristics also are important considerations in establishing the engineering properties and behavior characteristics of materials. The following briefly outlines some of the properties of particles and methods of classification for damsite investigations:

Size - The important classifications of size are: boulders, cobbles, gravel, sand, silt, and clay. Numerous grade scales have been developed to establish the limits of size for each of these classifications. The grade sizes used in the Unified Soil Classification System are to be used in the engineering geology phases of SCS work. Table 1-1 shows some of the commonly used grade scales for comparison.

Shape - Geologists express the degree of roundness of particles on the basis of the average radius of the corners divided by the radius of the maximum inscribed circle. Although particle shapes can be expressed numerically by this method, such a degree of accuracy is not required for geologic investigation of damsites. Visual estimation is sufficient for classification of equidimensional particles. Figure 1-1 shows a comparison of degrees of roundness and angularity which will serve as a guide to visual estimation and classification of roundness.

NATIONAL ENGINEERING HANDBOOK

SECTION 8

ENGINEERING GEOLOGY

Introduction

Purpose and Scope

The purpose of this part of the National Engineering Handbook is to present, in brief and usable form, information on equipment, tools, exploration and sampling techniques, and criteria for conducting adequate investigations of damsites. The material is compiled to assist technicians in planning site investigations, carrying out field investigations, and preparing reports within the framework of established SCS standards. The guide also will serve as a useful tool for training purposes and to promote extablishment of uniform standards and procedures for geologic investigations of damsites.

The choice of design and construction methods for a particular dam is contingent upon the characteristics of materials of which, and upon which, the structure is to be built. Knowledge of these materials, sufficient in scope and quality to satisfy design and construction requirements, is necessary for each site if consistent development of economically sound and practical structures is to be achieved. Such knowledge is acquired by thorough geologic examination of sites, by accurate foundation and borrow exploration, by soil mechanics laboratory tests, and thorough practical experience in a particular area.

This handbook is not intended to be a complete technical treatise on the subject of site investigations. Nor is it intended to establish a stereotyped pattern for site investigations. Each structure site has its own particular characteristics. The geologist and engineer must establish a pattern of investigations and application of exploration and sampling methods dependent on the site conditions, to obtain the information needed for design and construction. This requires sound judgment and a knowledge of requirements for design and construction as well as a knowledge of exploration and sampling techniques. The geologist must become thoroughly familiar with basic principles and techniques in the fields of engineering geology, soil mechanics, design, and construction, to achieve technical competence. He must work closely with the project, design, and construction engineers on each site in order to determine the requirements for that particular site and to establish investigational procedures.

Use of Earth Materials

The use of earth materials is stressed because they have three aspects of major importance: (1) The materials are usually present in abundance in the immediate area of the structure; (2) the materials have properties which permit their use for structural purposes; and (3) their availability allows a greater economy than manmade, imported materials.

Embankments

The use of natural materials in embankments is related to their inherent capacity to be remolded with, in some types, an accompanying modification in their engineering properties. Earth embankments may be homogeneous or zoned with the materials selected and remolded to form an essentially water-impervious barrier as well as a structurally strong unit.

Foundations

Materials composing foundations must support, without danger of failure, rupture, or displacement, the loads to be superimposed. The types of foundations range from bedrock to unconsolidated sediments and, as the types vary, so must the method and intensity of investigation vary.

Spillways

The spillway controls the rate of discharge through the structure. By virtue of its stability and resistance to erosion, the spillway insures the life of the entire structure. Earth spillways are susceptible to erosion. When they are to be constructed of, or in, erodible materials, great care should be given to the identification and classification of the materials.

Other Uses

Coarse-grained materials may be used for foundation and embankment drains and for erosion protection.

Riprap may be placed on the embankment so as to afford protection from the impact of water and weather.

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CHAPTER 1 - DESCRIPTION OF MATERIALS

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Table

Table 1-1. Comparison of Grade Scales

in.	UNIFIED	AASHO	AGU	WENTWORTH	mm.
	boulders	coarse gravel or stone		boulder gravel	4026
			very large boulders		2048
			large boulders		1024
			medium boulders		512
12			small boulders		256
6	large cobbles		large cobbles	cobble gravel	128
3	small cobbles		small cobbles		64
1	coarse gravel		very coarse gravel	pebble gravel	32
3/4		medium gravel or stone	coarse gravel		16
3/8	fine gravel		medium gravel		8
mm. 4.76	No. 4*	fine gravel or stone	fine gravel		4
2.00	coarse sand / No.10*		very fine gravel	granule gravel	2
1.00	medium sand	coarse sand	very coarse sand	very coarse sand	1
0.42	No.40*		coarse sand	coarse sand	1/2
0.25	fine sand	fine sand	medium sand	medium sand	1/4
0.125			fine sand	fine sand	1/8
0.074	No.200*		very fine sand	very fine sand	1/16
	silt or clay	silt	coarse silt	silt	1/32
			medium silt		1/64
			fine silt		1/128
		.005 mm.	very fine silt		1/256
		clay	coarse clay size	clay	1/512
			medium clay size		1/1024
		colloids	fine clay size		1/2048
			very fine clay size		

*U.S. Standard Sieve Number

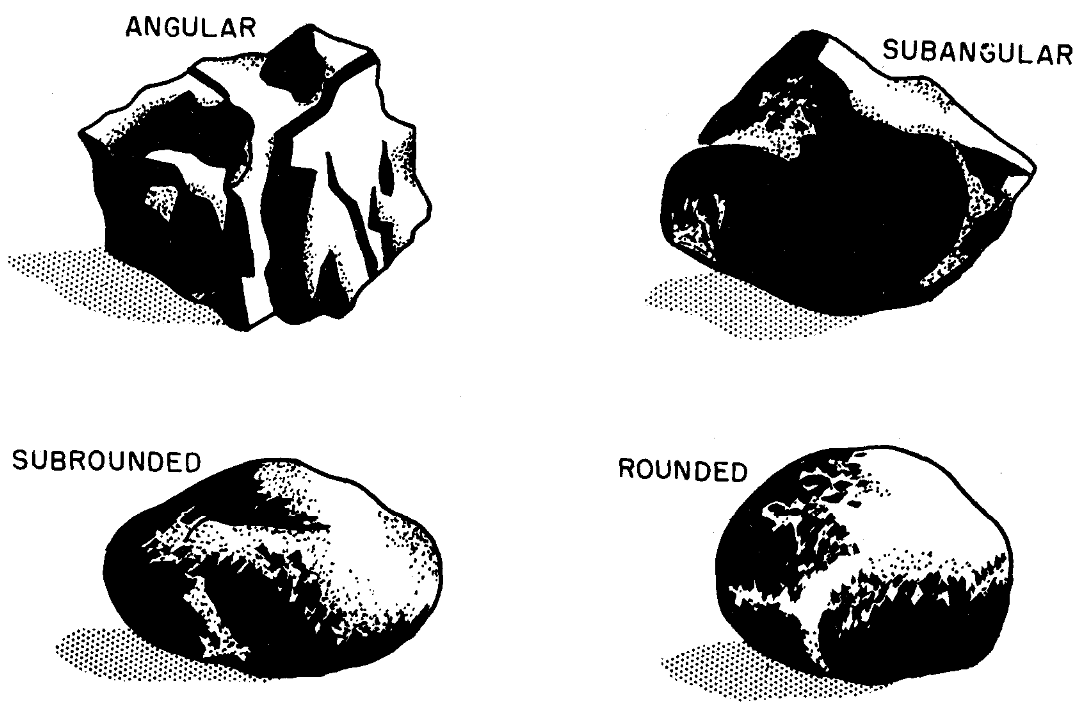

Figure 1-1 Particle Shapes

The above classification is adopted primarily to equidimensional particles of materials coarser than silt particles.

Normally it is not adequate for expression of non-equidimensional constituents either in coarse or fine-grained fractions of materials. Where flaky minerals are present these should be described on the basis of the mineral name instead of the shape, viz., biotite, muscovite, chlorite, etc. Where platy or prismatic rock fragments are present the rock type or structure controlling the shape such as bedding, cleavage, schistosity, etc., should be given as well as degree of rounding.

This classification is adopted primarily for equidimensional particles coarser than silt sizes. Normally, it is not adequate for expression of nonequidimensional constituents either in coarse or fine-grained fractions of materials. Where non-equidimensional minerals are present they should be described in such terms as platy, tabular, or prismatic. Where platy or prismatic rock fragments are present, the rock type or structure controlling the shape; such as bedding, cleavage, or schistosity; should be given as well as degree of roundness.

Mineral composition - The mineral composition of site materials varies greatly from place to place, depending upon the genesis of the materials and the geologic processes involved. The mineral composition may vary also with particle size at a particular site. The proportion of platy minerals usually increases over equidimensional minerals as the particle size decreases.

The coarse-grained materials are normally dominated by those rock-forming minerals, which are more resistant to chemical weathering, such as quartz and the heavy minerals. Rock fragments and unaltered rock-forming minerals, such as feldspar, calcite, and mica also may be present. The less complex minerals in the coarse-grained fractions can be identified readily by megascopic methods. Wherever this is possible, the predominant rock or mineral constituents and those rocks and minerals having a deleterious effect on engineering properties should be noted, using standard geologic terms.

The fine-grained materials represent the products of chemical and mechanical weathering. The mineral composition, together with weathering processes, controls the ultimate size and shape of the fine-grained particles. Quartz, feldspar, and many other minerals may, under mechanical weathering, be reduced to fine-grained equidimensional particles, such as in rock flour. Some types of minerals are broken down mechanically into platy particles. Micas are of this type. Alteration products of other types of minerals may result in the formation of platy particles.

Clay minerals - A group of minerals, known as clay minerals, requires special attention because of the influence of individual minerals on the engineering properties of soils. This is brought about by their inherently fine-grained nature, platy shape, and molecular structure. Clay minerals are predominantly hydrous aluminum silicates or more rarely, hydrous magnesium or iron silicates. Clay minerals are composed of layers of two types: (1) silicon and oxygen (silica layer) and (2) aluminum and oxygen or aluminum and hydroxyl ions (alumina or aluminum hydroxide layer).

There are three principal groups of clay minerals: kaolinites, montmorillonites, and illites. Because of variable influence of each type on the engineering property of soils, it is important that the predominant clay mineral be properly identified whenever possible.

The kaolinite clays consist of two layer molecular sheets, one of silica and one of alumina. The sheets are firmly bonded together with no variation in distance between them. Consequently the sheets do not take up water. The kaolinite particle sizes are larger than those of either montmorillonite or illite and are more stable.

The montmorillonite clays consist of three layer molecular sheets consisting of two layers of silica to one of alumina. The molecular sheets are weakly bonded, permitting water and associated chemicals to enter between the sheets. As a result, they are subject to considerable expansion upon saturation and shrinkage upon drying. Particles of montmorillonite clay are extremely fine, appearing as fog under the high magnification of the electron microscope. Montmorillonite clays are very sticky and plastic when wet, and are of considerable concern in respect to problems of shear and consolidation.

Illite has the same molecular structure as montmorillonite but has better molecular bonding, resulting in less expansion and shrinkage properties. Illite particles are larger than montmorillonite and adhere to each other in aggregates.

Hardness - The hardness of individual minerals is normally expressed by geologists by means of the Mohs scale. Hardness, along with color, luster, transparency, streak, crystal form, cleavage or fracture, and specific gravity is an important property for identification of minerals. Hardness of individual particles is an important engineering consideration in respect to resistance to crushing when loaded.

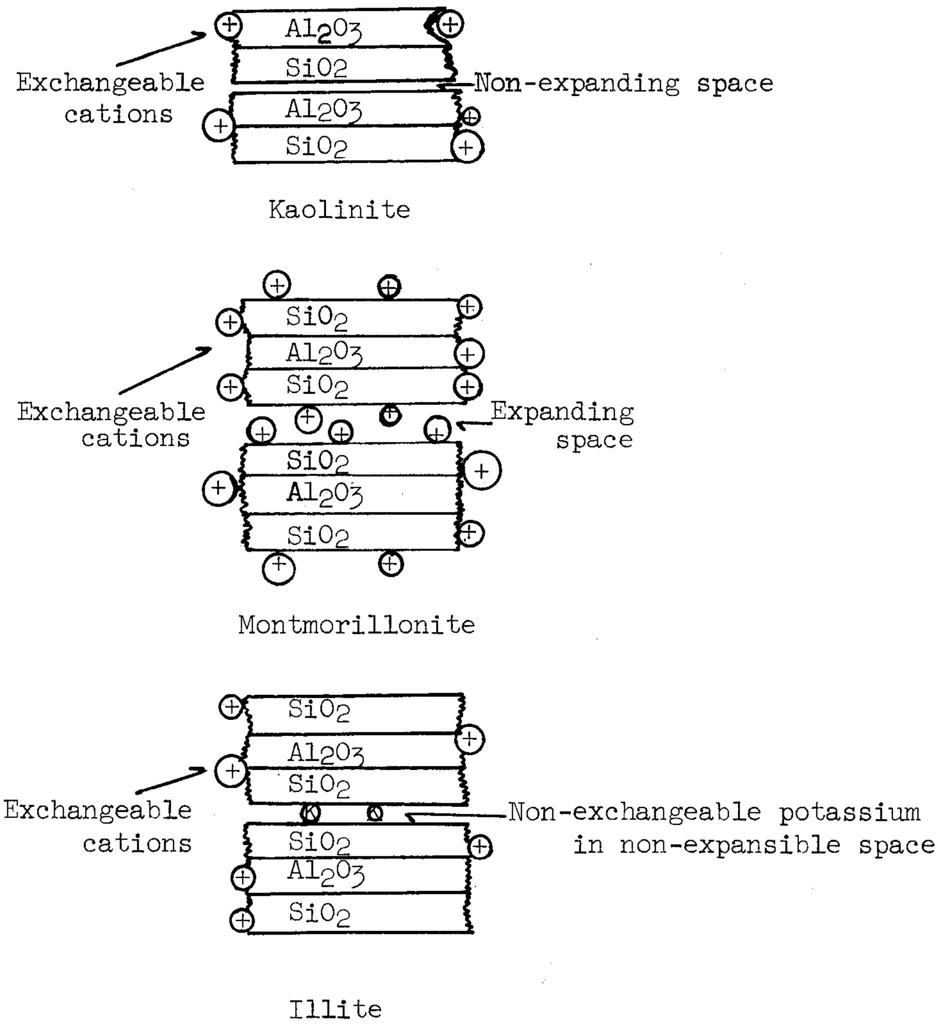

Figure 1-2. Representation of the Structure of Clay Mineral Particles

(From J. G. Cady, "Characteristics and Behavior of Soil Clay, SCS, 1954)

Mass Characteristics

Although individual particle characteristics are important for identification purposes and have an influence on engineering properties, associations of different particles impart mass characteristics and properties to both rock and soil materials, which are entirely different from those of the individual particles. This section briefly outlines mass characteristics which need to be described to develop adequate interpretations for geologic engineering purposes.

Soil materials - The term "soil materials" is here defined as the unconsolidated products of erosion and decomposition of rocks. It may include organic material. "Soil material" or "soil" consists of a heterogeneous accumulation of mineral grains, including most every type of uncemented or partially cemented inorganic and organic material to be found on the earth's surface. Soil materials may be referred to as cohesive or noncohesive, depending upon the tendency of the particles to adhere to one another.

Consistency - With increasing water content a solid clay mass changes consistency and passes from a solid state through a semisolid and plastic to a liquid state. The moisture contents, expressed in percent of dry weight, at which the mass passes from one of these stages of consistency to another are known as the Atterberg limits or limits of consistency.

The term consistency also is used to describe the relative ease with which a saturated cohesive soil can be deformed. In this sense, the consistency is described as very soft, soft, medium, stiff, very stiff, and hard.

The Atterberg limits or limits of consistency are determined on soil materials passing the 40-mesh sieve. The shrinkage limit or the limit between the solid and semisolid states is the maximum water content at which a reduction in water content will not cause a decrease in volume of the soil mass.

The plastic limit is the water content corresponding to an arbitrary limit, fixed by a standard testing procedure, between the semisolid and plastic states of consistency.

The liquid limit is the water content corresponding to the arbitrary limit, fixed by a standard testing procedure, between the plastic and liquid states of consistency.

The plasticity index is a measure of the plastic state or the range of consistency within which a soil exhibits plastic properties and is numerically equal to the difference between the liquid limit and the plastic limit.

Density - The density or unit weight of a soil is defined as the weight per unit volume. The dry density is the weight of the unit mass excluding the weight of the contained water. The wet density includes the weight of the contained water.

Moisture content - The moisture content is the ratio of the weight of water contained in the soil to the dry weight of the soil solids. This value is expressed as a percent.

Density, or unit weight, and moisture values are highly significant in embankment construction. A certain density may be specified to which the soil is to be compacted, and the moisture content at the time of compaction is very important for many soils.

Permeability - The permeability of a soil is its capacity to transmit fluids under pressure. It may vary in different directions. The water flows through the voids between the soil grains. Therefore, the larger the size of the pores and their interconnections, the greater the flow of water. It may be seen that coarse-grained soils are more permeable than fine-grained soils. A well-graded soil, having a good distribution of particle size from large to very fine, is relatively less permeable than a poorly-graded soil of a comparable size because the finer grains fill the space between the larger particles.

Coefficient of permeability - The coefficient of permeability of a given soil is the volume of flow of water through a unit area, in unit time, under unit hydraulic gradient and at a standard temperature. Area is measured at right angles to the direction of flow. There are many permeability units in use. The more common ones are:

Meinzers Units = gallons/ft^2/day under unit hydraulic gradient.

Feet/day = ft^3/ft^2/day under unit hydraulic gradient.

Cm/second = cm^3/cm^2/sec. under unit hydraulic gradient.

Feet/year = ft^3/ft^2/year under unit hydraulic gradient.

Inches/hour = $inch^3/inch^2$/hour under unit hydraulic gradient.

All units are for a standard water temperature. For precise measurements, correction to this temperature must be made. Unit head or unit hydraulic gradient is a gradient of 1:1 or 100 percent.

These units are readily interchangeable by multiplying by the proper factor as indicated in table 1-2.

Table 1-2. Conversion factors for permeability units

From \ To	Meinzers Units	Feet/day	Cm/sec.	Feet/year	Inches/hour
Meinzers Units	1.0000	0.13368	4.7159×10^{-5}	48.8256	0.06684
Feet/day	7.4806	1.0000	3.5278×10^{-4}	365.2422	0.50000
Cm/sec.	2.12049×10^{4}	2.83464×10^{3}	1.0000	1.03530×10^{6}	1.41731×10^{3}
Feet/year	0.02048	2.7379×10^{-3}	9.6590×10^{-7}	1.0000	1.3689×10^{-3}
Inches/hour	14.9611	2.0000	7.0556×10^{-4}	730.4844	1.0000

Consolidation - Consolidation refers to the volume change of a soil under load. Normally fine-grained soils consolidate more than coarse-grained soils and poorly-graded soils consolidate more than well-graded soils. Density, plasticity, porosity, permeability, and organic content are important factors in determining the degree of compressibility.

Shearing strength - Shearing strength is the resistance of soil particles to sliding upon one another.

Gradation - The term gradation is used here to describe the grain size distribution of unconsolidated or soil materials in keeping with engineering terminology. For engineering purposes the fine fraction (200 mesh) is classified as silt or clay on the basis of plasticity rather than on grain-size diameter.

This system is not entirely adequate to define all of the physical characteristics needed for identification and correlation purposes. The system to be used for geologic purposes consists of classification based primarily on the relative proportions of gravel, sand, silt, and clay. These classifications are outlined in figure 1-3.

Texture - Texture is defined as the geometrical aspects of the component particles of a rock, including size, shape, and spatial arrangement. Texture is important for field identification purposes and for predicting behavior of rock under load. Although specific geologic terms such as "phaneritic" and "aphanitic" imply specific descriptions of igneous rock, simpler terms such as "coarse-grained" and "fine-grained" should be employed to be more understandable. It is often more important to describe the presence of mineral constituents, degree of cementation, conditions of weathering, fracture system, and other properties having an influence on engineering properties, than to identify the type of rock. The symbols contained in figure 1-3, "Standard SCS Geologic Symbols" constitute a coverage normally adequate for classifying and describing rocks.

Rock structure - The structure of rocks can usually be given in a few simple terms describing holes, cavities, joints, bedding planes, fractures, cleavage, schistosity and similar features. Use of terms such as "vesicular" or "vugs" should be avoided where possible and always defined when used. Rock structure is an important consideration in respect to the amount and direction of water movement.

Strength of rock - The strength of rock is influenced by the mineralogical composition, shape of grains, texture, crystallinity, stratification, lamination, and other factors. Secondary processes such as cementation and weathering have a profound influence on the strength of rock. The following classifications,

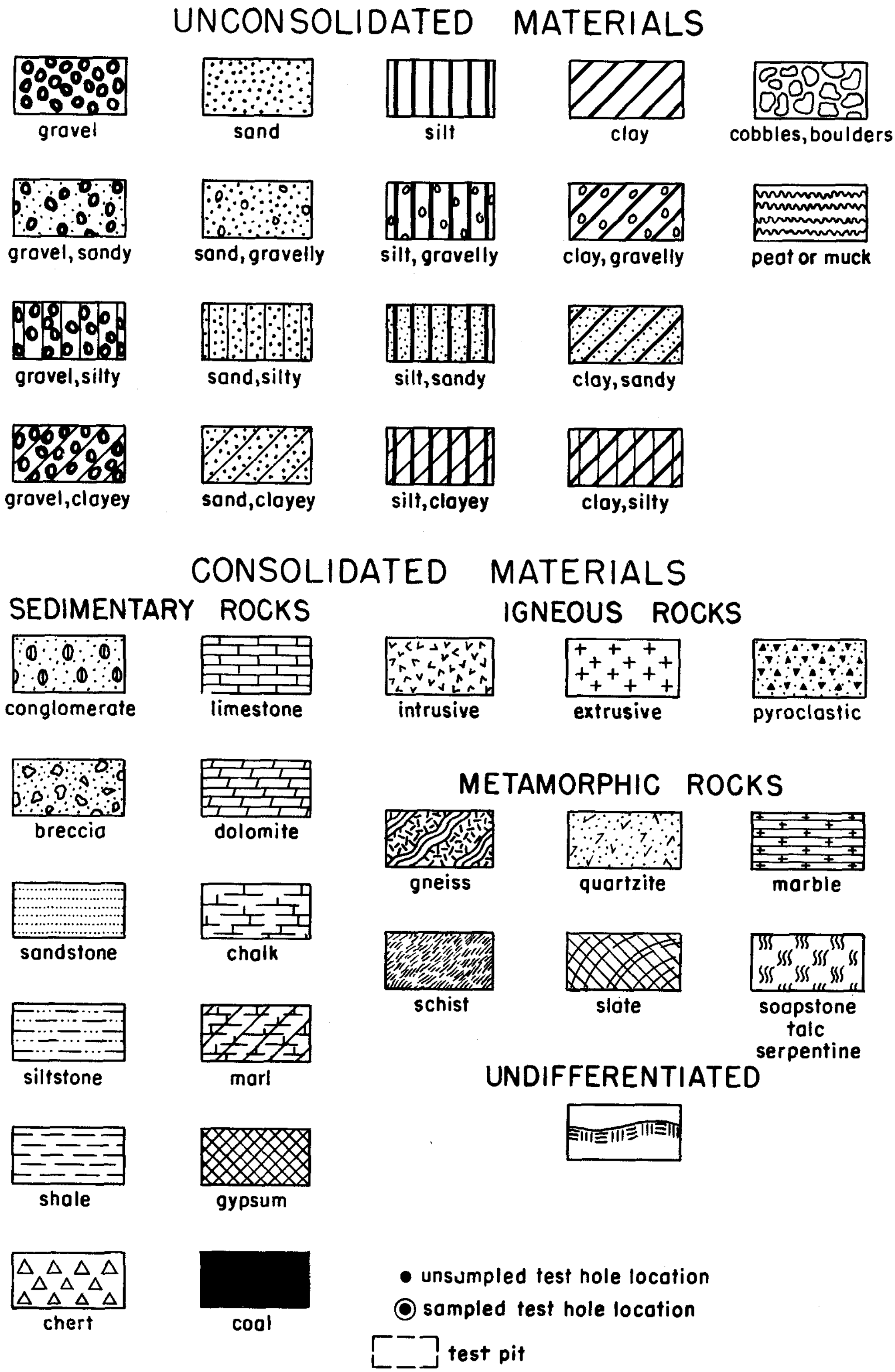

Figure 1-3. Standard SCS Geologic Symbols

based on field tests, are to be used for describing rock strength:

Very Soft - Permits denting by moderate pressure of the fingers.

Soft - Resists denting by the fingers, but can be abraded and pierced to a shallow depth by a pencil point.

Moderately Soft - Resists a pencil point, but can be scratched and cut with a knife blade.

Moderately Hard - Resistant to abrasion or cutting by a knife blade but can be easily dented or broken by light blows of a hammer.

Hard - Can be deformed or broken by repeated moderate hammer blows.

Very Hard - Can be broken only by heavy, and in some rocks, repeated hammer blows.

Cementation of rock is an important secondary process influencing the strength of rock. The principal cementing materials are silica, calcium carbonate, iron oxide, and clays. Most durable are bonds of silica, whereas clay bonds are weakest, particularly when saturated. It is important, therefore, to note the nature of cementing material when describing rock.

Chemical weathering occurs primarily through processes of hydration, oxidation, and carbonation. Chemical weathering not only influences strength of rocks but also the characteristics of soil materials derived therefrom. As a result of chemical weathering certain rocks break down into equidimensional grains whereas others break down into platy grains such as the clay minerals. Rocks, which contain minerals of variable resistance to chemical weathering, may become highly permeable through the alteration and removal of easily weathered materials and leaving the more resistant materials. The circulation of meteoric waters through fractured limestone and similar materials may develop solution channels of such large dimensions that collapse of foundations may be of concern. The products of chemical rock weathering have entirely different engineering properties than the rock from which they are derived. It is important, therefore, that the extent and character of these products be adequately described.

The strength of rock masses is greatly influenced by the presence of bedding, cleavage, schistosity, and similar features as well as by the presence of breaks such as joints and fractures. The spacing, pattern, attitude, and other characteristics of these features must be considered in evaluating strength of a rock mass. It is important that these characteristics be adequately described in describing rock masses.

Rock characteristics related to engineering properties - The character of rock is important from the standpoint of permeability, consolidation, shearing resistance, durability, and workability. The cost of structures may be greatly influenced by expensive rock excavation and by need for treatment of foundations, abutments, and reservoir basins. It is important, therefore, that where such problems exist, they be recognized and adequately described.

Foundations, abutments, and reservoir basins which are highly fractured, which contain solution channels, or are the products of differential weathering may be highly permeable. Practically all rocks have fractures. A rock mass, having extremely low porosity, might be highly permeable due to fractures and joints. Jointing is not restricted to any particular type of rock, but certain types of rocks in a particular area may possess a tendency toward larger and more closely spaced fractures than other types. Differential weathering may be found in many types of igneous and metamorphic rocks and certain sedimentary rocks. Differential weathering of cherty limestones, for example, may result in highly permeable rock foundations. It is important that the rate of permeability and the depth and direction of water movement be determined as closely as possible in order to determine requirements for foundation treatment. Field investigation may require angular boring, pressure testing, use of dyes or other tracer compounds, or other methods to properly determine permeability of rock.

The bearing strength of rock is normally adequate to support dams designed by the SCS. However, consolidation may be a problem in certain types of rock such as weakly cemented shales and siltstones, and rocks which have been altered to clay minerals. In each instance, samples of questionable materials are to be obtained for laboratory analysis, following the same procedures used for soil materials. Caverns or mines may present a problem of bearing or stability depending on the size and location of openings.

Problems of shear may result from poorly cemented shales and siltstones or highly weathered rock of low shear strength. Particular attention must be given to materials which dip in an adverse direction and which are subject to saturation or to unloading of their toe supports by excavation. This includes strata dipping downstream in foundations or strata dipping toward the centerline (parallel to the slope of the abutment) of proposed emergency spillway excavations. Rock strata of low shear strength must be thoroughly delineated and evaluated for design and construction purposes.

Cost of rock excavation may be greatly influenced by the nature of rock and secondary alteration. "Common excavation" and "rock excavation" are separate bid items for construction contracting. The geologist must describe rock proposed for excavation in terms translatable into workability by construction equipment so that the amounts of common and rock excavation can be determined in developing invitation for bids. For further details on classification of common and rock excavation, see SCS Standard Specifications, Construction and Construction Materials, Section 4-58, Item 4.2.

The following general descriptions of rock in terms of workability will prove helpful to geologists in describing rock proposed to be excavated and to contracting officers in interpreting descriptions for developing specific bid items. Very soft and soft rocks (See p. 1-13) can be excavated by power shovels or bulldozers in practically all cases, if the entire excavation is in the formation. Power shovels can excavate moderately soft formations and heavy power shovels can excavate moderately hard rocks. Moderately soft and moderately hard rocks have some degree of cementation and include partly cemented sandstones and marls and fairly compact shales. Most formations of hard rocks and those of very hard rocks must be removed by blasting if they have considerable bulk or thickness. Stratigraphy, attitude, and jointing are important factors in developing construction methods. Thus, thin beds of hard and very hard rocks may be removed by ripper, rock plow, or power shovel if they occur in beds of not more than 6 or 8 inches in thickness or are highly jointed. Hence, a series of soft shales interbedded with 6-inch layers of hard or very hard limestones usually can be removed with a power shovel. On the other hand, a massive bed of shale or crystalline gypsum 6 feet or more thick may require blasting, although neither would be rated higher than moderately soft.

Color - Color varies widely in materials but often provides a useful means of identification for geologic and engineering purposes. Thus, the presence of organic matter, certain minerals, and some types of weathering can often be readily detected by color. In classifying color of materials, care should be used to determine whether the coloring is due to inherent color of constituents, superficial stain or tarnish, or a weathering product. There may be a marked difference of color, depending on whether the material is dry or wet.

Geologic Properties of Materials

Stratigraphy

Stratigraphy deals with the formation, composition, thickness, sequence, and correlation of materials. Knowledge of the stratigraphy such as the continuity or discontinuity of certain beds or the distribution of critical horizons may be very important in interpreting site conditions.

Stratigraphy of the site is established from the study of particle and mass characteristics and the interpretation and extrapolation of the boring and test hole data. The determination of stratigraphy involves consideration of particle characteristics, their origin, mode of transportation (wind, water, ice, gravity) and the processes of deposition and consolidation. Guiding factors are the petrographic characteristics of the materials; e.g., mineral composition, size, shape, and spatial arrangement of the particles; and the type age, depth, thickness, sequence and continuity of the deposits.

Type of deposit - Type of deposit involves the mode, agent, and processes of formation of the deposit. It furnishes information on the continuity of strata and the uniformity of physical characteristics which may be encountered. For example, deposits of loess and glacial lake deposits (varved clays) may be remarkably consistent in thickness of strata and physical characteristics of materials. Other types, such as stream bar deposits, may pinch out in a matter of a few feet and the particle characteristics vary widely over short distances. It is important, therefore, that the type of deposit be accurately described in order to properly extrapolate continuity and physical characteristics of materials.

Standard geologic terms, simplified to the extent possible for adequate interpretations, should be used to describe the type of deposit. Such terms as granite, volcanic ash, marl, limestone, and gneiss, along with the formation name or age, are commonly used to describe rock materials. Because of the highly variable characteristics of sediments, however, a greater breakdown of terms which imply mode of origin should be employed. Such deposits should be described as fan, dune, colluvium, stream channel and other types denoting origin, in order to properly interpret physical characteristics.

Age - The age of a stratum establishes its vertical position in the geologic column and its relationship to other strata. Age should always be indicated using accepted geologic eras, periods, epochs, and ages when identifiable.

Depth, thickness, and continuity - The depth and thickness of materials at specific points at a site are determined from exposure and subsurface boring or test holes. Continuity must be interpreted on the basis of depth, thickness, type, and similarity of deposits and particle and bulk characteristics measured and described at different observation points. To facilitate interpretation of continuity, all measurements of depth should be referenced to a common elevation based either on mean sea level or an assumed datum plane. It is important that the vertical and areal continuity be determined for those materials which may have an effect on the design and construction of a dam. Continuity is best established on a graphic basis.

Depth and thickness of identified strata are to be plotted on graph paper at their proper elevations. Continuity lines are to be drawn in (dashed) where correlation of similar strata from different bore holes is possible. Forms SCS - 35A, 35B, 35C, and 35D, "Plan and Profiles for Geologic Investigation," are provided for this purpose. For examples, see chapter 4, figure 4-1. If a stratum in the vertical column of one observation cannot be correlated with any stratum in the next column, continuity has not been established. If correct interpretations have been made, the particular stratum is considered to be discontinuous. This should be shown by correlation lines which pinch out between bore holes. Discontinous strata are a common occurrence in types of materials having lenticular beds or where faults or other structural movements have resulted in shifting of beds to positions where they are not concordant. Whenever the limits of continuity cannot be established, and the discontinuity cannot be accounted for in the interpretations, additional observations are needed until sufficient exploration has been done to confirm lateral and longitudinal continuity or discontinuity.

Structure

The geologic structure of the site is of primary consideration in site selection. The term "structure" as applied to the geology of a damsite, refers to all of the geologic structural features either at the damsite or influencing the site. These features include faults, folds, unconformities, joints, fractures, rock cleavage, etc. Structure has an important influence on the geologic conditions of a site and the ultimate stability and safety of an engineering structure. Problems of leakage, sliding of embankments, uplift pressure in foundations, and differential settlement are often traced back to inadequate delineation and consideration of the geologic structure at the site.

Attitude - Attitude implies the geometric alinement of strata, faults, fractures, and other features, and is usually expressed in terms of dip and strike. In some instances, such as in plunging anticlines, for example, special conditions require more elaborate descriptions than dip and strike. In describing attitude, standard geologic terms should be used.

Folds - Folding is a common type of deformation in the earth's surface. Many folds extend over large areas so that deformation results in a more or less uniform dip and strike at a particular site. Smaller, local folds, however, are usually of more concern than those of a regional character. Minor folds which create channels with capacity for substantial subterranean water movement may escape detection in a geologic investigation of a damsite. Where such folds are suspected and anomalies of continuity in respect to apparent inclination of strata in bore holes are encountered, additional borings may be required to determine the location and size of the folds for design considerations. Descriptions of folds should indicate their size, location, type (anticlinal, synclinal, drag) and the attitude of the limbs and axial plane.

Faults - A fault is defined as a break in the earth's crust along which movement has taken place. Displacement may be but a few inches or many miles. Faults may be detected by discontinuity of strata and by surface features. Aerial photographs often provide evidence of the presence of faults in an area. Faults may present a serious problem when they occur at a structural site. One that is active obviously presents a serious hazard. In addition, those that are now inactive may have so modified the geology that the site presents special problems in design, construction, or functioning of the proposed structure. Faults encountered at sites should be described in detail, including type, such as normal or reverse, attitude of the fault plane and the direction and amount of displacement. Juxtaposition of materials with quite different engineering properties and modification of ground water conditions are examples of the effects of faulting that may be important. Furthermore, the fault zone is of special importance if appreciable rock shattering or alteration of minerals has occurred, or if appreciable gouge has formed. In these instances, the approximate dimensions of the fault zone should be determined and changes in character of materials described.

Joints - Joints are defined as breaks in the rocks of the earth's crust along which no movement has occurred. Joints usually occur in systematic patterns. They may allow movement of ground water through otherwise impermeable material and this in turn may create problems in design, construction, or functioning of the structure. The number and orientation of joint systems and their spacing also influences the ease of rock excavation. Description of joints should include, besides their attitude, the spacing and the estimated depth of jointing, type of joints (strike, dip, or oblique,) and kind of joint system.

Paleontology

Evidences of life in the past are important for correlation purposes to establish continuity. Fossils are keys to correlation of rock strata. The presence of artifacts may be a means of distinguishing between Recent and Modern sediments. Plant and animal remains may have a very marked influence (usually adverse) on engineering properties. Thus, peat, muck, and carbonized plant remains have little value as construction materials. Tests or shells of foraminifera, algae, coral, and other components impart specific behavior characteristics to engineering materials. Descriptions of artifacts and fossils, where they have little or no influence on the engineering properties of materials, should be limited to brief notes needed for correlation purposes. More detailed descriptions are needed where such materials have an influence on the engineering properties. These should include description of the nature of materials, including name, their extent and distribution in the formation.

Field Tests

The geologist may need to make field tests to further delineate geologic properties and to classify materials more accurately. The classification of unconsolidated materials for engineering purposes is done according to the Unified Soil Classification System, using standard tests developed for this purpose. These standard tests are described in the section on the Unified Soil Classification System. In addition to these standard tests, additional tests may be employed to aid in classifying materials and identifying special properties. Some of the tests are described below.

Acid test - Effervescence when a drop of dilute hydrochloric acid (one-tenth normal) is placed on a soil or rock indicates the presence of calcium carbonate.

Trailing fines - When a small sample of pulverized dry soil is shaken in the palm of the hand at a slight angle, the fine portion will trail behind. This is an aid in determining the relative proportion of the various grain sizes.

Shine test - When a dry or moist lump of soil is cut with a knife, a shiny surface indicates the presence of plastic clay.

Taste test - A dry lump of soil with a high clay content will adhere to the tongue.

Ribbon test - Plastic clays, when squeezed between the finger and thumb with a sliding motion, form a ribbon. The strength of the ribbon is an indication of the plasticity of the soil.

Odor - Organic soils have a pronounced and distinctive odor. Heating may intensify organic odors.

Acetone test - If gypsiferous soils are suspected, it may be necessary to conduct the following simple test:

1. Place 0.20 pound of air dry soil in a one-quart bottle and fill the bottle with distilled water.

2. Shake the soil-water mixture for about 20 minutes and then allow it to settle for 10 or more hours.

3. After this settling period, the solution above the soil will be clear if the soil contains significant amounts of gypsum. If the solution is cloudy, significant amounts of gypsum probably are not present.

4. Carefully pour about 1/2 ounce of the clear solution into a glass container without disturbing the settled soil in the bottom of the bottle.

5. Test this 1/2 ounce of solution for gypsum by adding 1/2 ounce of acetone to the solution. The presence of a milky, cloudy precipitate in the test solution indicates gypsum.

Crystal-violet test - The crystal-violet staining solution causes montmorillonite to appear green at first and then change to a greenish yellow or orange yellow. The sample must be treated with hydrochloric acid prior to applying the stain. With this test illite attains a dark green color. Kaolinite merely absorbs the violet dye. The test solution consists of 25 cc of nitrobenzene and 0.1 gram of crystal violet.

Malachite-green test - Clay minerals of the kaolinite group (when treated with hydrochloric acid) show a bright apple-green color after application of malachite green solution. The solution consists of 25 cc of nitrobenzene and 0.1 gram malachite green. Montmorillonite and illite clays usually show greenish yellow or pale yellow.

Unified Soil Classification System

The Unified Soil Classification System provides a method of grouping unconsolidated earth materials according to their engineering properties. It is based on soil behavior, which is a reflection of the physical properties of the soil and its constituents. This system has been accepted as a tentative standard by the ASTM and given designation D2487 (laboratory method) and D2488 (field methods).

For the purpose of classification, the system established 15 soil groups, each having distinctive engineering properties. Boundary classifications are provided for soils which have characteristics of two groups.

Letter symbols have been derived from terms which are descriptive of the soil components, gradation, and liquid limit. These are combined to identify each of the 15 soil groups. Table 1-3 lists these letter symbols.

Table 1-3. Letter Symbol

Component		Modifier	
Letter Symbol	Name	Letter Symbol	Name
None	Boulders or Cobbles	W	Well graded
G	Gravel	P	Poorly graded
S	Sand	M	Silty
M	Silt	C	Clayey
C	Clay	H	High liquid limit
O	Organic	L	Low liquid limit
Pt	Peat	---	---

<u>Soil Components</u>

The term "soil components" has been given to the solid mineral grains of which earth materials are composed. They range in size from over 12 inches average diameter to colloidal size. The particle size, gradation, shape, and mineral composition affect the behavior of the soil, as do the moisture content and the inclusion of other materials such as organic matter, gases, and coatings of cementing minerals. Table 1-4 lists various soil components with their associated grain sizes and descriptions and enumerates some of their significant properties. Comparison of grain size boundaries of the Unified System with those of other commonly used grade scales is shown in table 1-1.

Table 1-4

Soil Components and Significant Properties 1/

Soil Component	Symbol	Grain size range and description	Significant properties
Boulder	None	Rounded to angular, bulky, hard, rock particle, average diameter more than 12 in.	Boulders and cobbles are very stable components, used for fills, ballast, and to stabilize slopes (riprap). Because of size and weight, their occurrence in natural deposits tends to improve the stability of foundations. Angularity of particles increases stability.
Cobble	None	Rounded to angular, bulky, hard, rock particle, average diameter smaller than 12 in. but larger than 3 in.	
Gravel	G	Rounded to angular, bulky, hard, rock particle, passing 3-in. sieve (76.2 mm) retained on No. 4 sieve, (4.76 mm).	Gravel and sand have essentially same engineering properties differing mainly in degree. The No. 4 sieve is arbitrary division, and does not correspond to significant change in properties. They are easy to compact, little affected by moisture, not subject to frost action. Gravels are generally more pervious, stable, and resistant to erosion and piping than are sands. The well-graded sands and gravels are generally less pervious and more stable than those which are poorly graded. Irregularity of particles increases the stability slightly. Finer, uniform sand approaches the characteristics of silt; i.e., decrease in permeability and reduction in stability with increase in moisture.
Coarse		3 - 3/4 in.	
Fine		3/4 in. to No. 4 sieve (4.76 mm).	
Sand	S	Rounded to angular, bulky, hard, rock particle, passing No. 4 sieve (4.76 mm) retained on No. 200 sieve (0.074 mm).	
Coarse		No. 4 to 10 sieves: 4.76 to 2.0 mm.	
Medium		No. 10 to 40 sieves: 2.0 to 0.42 mm.	
Fine		No. 40 to 200 sieves: 0.42 to 0.074 mm.	
Silt	M	Particles smaller than No. 200 sieve (0.074 mm) identified by behavior; that is, slightly or non-plastic regardless of moisture and exhibits little or no strength when air dried.	Silt is inherently unstable, particularly when moisture is increased, with a tendency to become quick when saturated. It is relatively impervious, difficult to com highly susceptible to frost heave, easily erodible and subject to piping and boiling. Bulky grains reduce compressibility; flaky grains, i.e., mica, diatoms, increase compressibility, produce an "elastic" silt.
Clay	C	Particles smaller than No. 200 sieve (0.074 mm) identified by behavior; that is, it can be made to exhibit plastic properties within a certain range of moisture and exhibits considerable strength when air dried.	The distinguishing characteristic of clay is cohesion or cohesive strength, which increases with decrease in moisture. The permeability of clay is very low. It is difficult to compact when wet and impossible to drain by ordinary means, when compacted is resistant to erosion and piping, is subject to expansion and shrinkage with changes in moisture. The properties are influenced not only by the size and shape, (flat, plate-like particles), but also by their mineral composition; i.e., the type of clay-mineral, and chemical environment or base exchange capacity. In general, the montmorillonite clay minerals have greatest, and kaolinite the least adverse effect on the properties of soils.
Organic Matter	O	Organic matter in various sizes and stages of decomposition.	Organic matter present in even moderate amounts increases the compressibility and reduces the stability of the fine-grained components. It also may decay, causing voids, or by chemical alteration change the properties of a soil. Hence organic soils are not desirable for engineering uses.

1/ Adopted from Use of the Unified Soil Classification System by the Bureau of Reclamation, A. A. Wagner, Fourth International Conference on Soil Mechanics and Foundations, London, England, August 1957.

A 1/4-inch is approximately equivalent to the No. 4 U. S. Standard sieve. The No. 200 U. S. Standard sieve size is about the smallest particle visible to the naked eye. The No. 40 sieve size is the limit between medium and fine sand and "Atterberg limit" tests are performed on the fraction finer than the No. 40 sieve size in the laboratory.

Gradation

Well graded - Soils which have a wide range of particle sizes and a good representation of all particle sizes between the largest and the smallest present are said to be well graded.

Poorly graded - Soils in which most particles are about the same size or have a range of sizes with intermediate sizes missing (skip grades) are said to be poorly graded.

The gradation or grain-size distribution of soils consisting mainly of coarse grains is diagnostic of the physical properties of the soil. However, gradation is much less significant for predominantly fine-grained soils.

In the soil mechanics laboratory, the amounts of the various sized grains are determined by sieving and mechanical analysis and the results plotted on form SCS-353. The type of gradation is readily apparent from the shape of the grain-size curve. Figure 1-4 illustrates the grain-size distribution graphs of some typical soils. Poorly graded soils have steeply sloping curves, very flat curves, or abrupt changes in the slope of the curves, when plotted on semi-log graph paper. Well graded soils plot as smooth curves. To qualify as well-graded, the gradation must meet certain requirements in respect to coefficient of uniformity and coefficient of curvature of the plotted graph. The coefficient of uniformity (C_u), which is a measure of size range of a given sample, is the ratio of that size, of which 60 percent of the sample is finer (D_{60}); to that size, of which 10 percent of the sample is finer (D_{10}). The coefficient of the curvature (C_c), which defines the shape of the grain-size curve, is the ratio of the square of that size, of which 30 percent of the sample is finer (D_{30}), to the product of the D_{60} and D_{10} sizes. These ratios can be simply written:

$$C_u = \frac{D_{60}}{D_{10}} \qquad\qquad C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}}$$

See table 1-5 for explanation of the use of these coefficients and other criteria for laboratory identification procedures.

Consistency

The most conspicuous physical property of the fine-grained soils is their consistency which relates to plasticity or lack thereof.

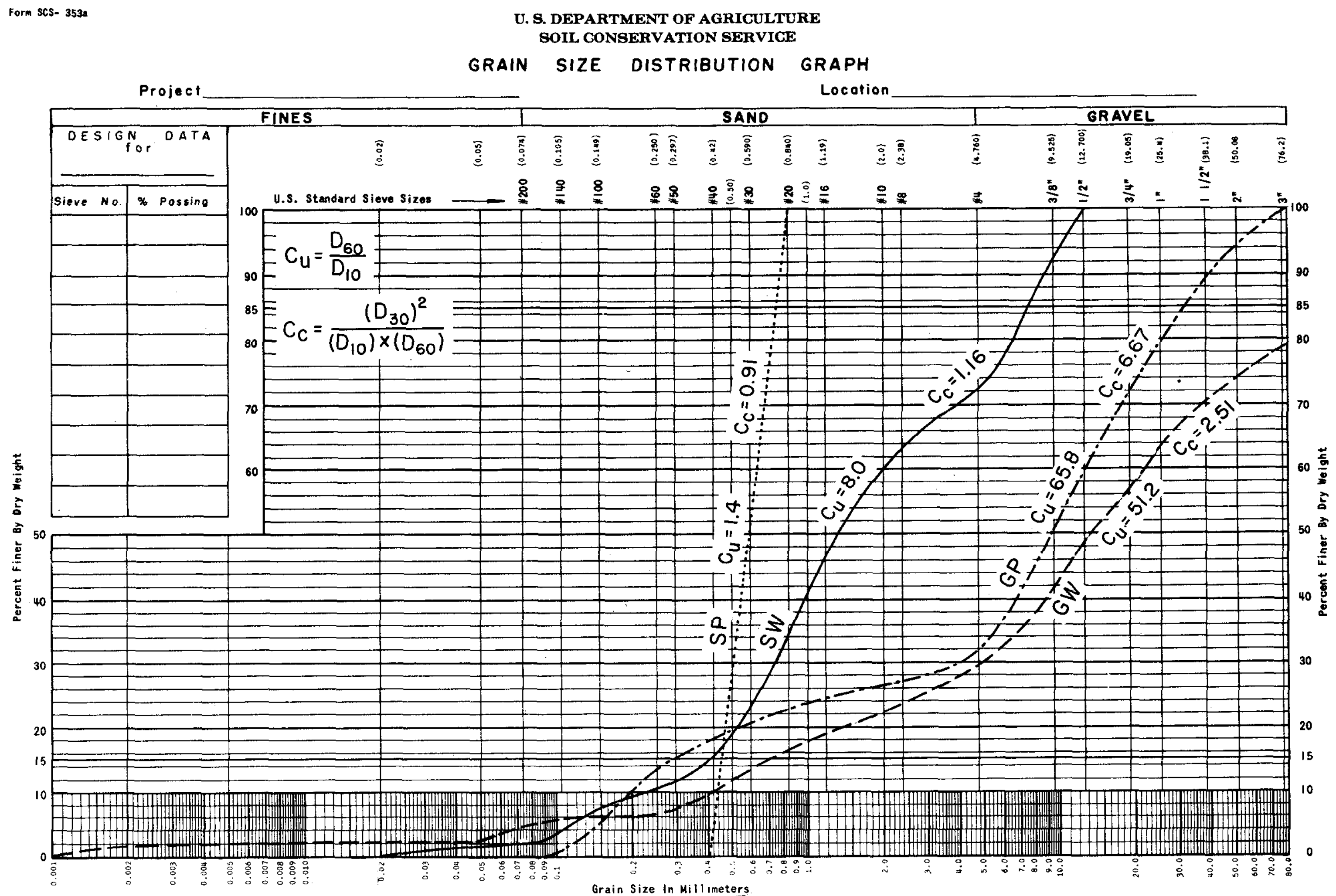

Figure 1-4- Grain Size Distribution Graph

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The various stages of consistency have been described under Mass Characteristics. Atterberg tests are used to determine the liquid and plastic limits of soils in the laboratory. Field tests for dilatancy (reaction to shaking), dry strength (crushing characteristics), and toughness (consistency near the plastic limit) have been devised for field determinations. Tables 1-6 and 1-7 contain the procedures for making these field determinations and the methods of field classifications. The tests are illustrated in figure 1-5.

Field Classification Procedures

An adequate description of the soil material encountered in a geologic investigation is very important. Such characteristics as approximate percentage of the sizes, maximum size, shape, and hardness of coarse grains; mode of origin, and type of deposit; structure; cementation; dispersion; moisture and drainage conditions; organic content; color; plasticity; and degree of compaction; in addition to typical name and group symbol, should be recorded in accurate and precise but simple terms. Local or geologic names should be included also where possible.

The field procedure does not require specialized equipment. A supply of clear water in a syringe or oil can and small bottles of dilute hydrochloric acid, acetone, and other reagents will facilitate the work. The geologist who lacks experience in classifying materials in the Unified Soil Classification System will find it expedient to use No. 4, No. 40, and No. 200 U. S. Standard Sieves in the field in the initial stages of training to aid in identifying relative quantities of coarse and fine-grained samples. Identification without the aid of sieves becomes relatively easy with practice and experience.

A representative sample is required for classification. The average size of the largest particle is estimated. The boulders and cobbles are removed and the percentage by weight in the total sample is recorded. The amount of over-sized material may be of importance in the selection of sources for embankment material. The distribution of boulders and cobbles and an estimate of their percentage in foundation materials should be noted so that their effect on the physical properties of the materials and possible construction problems can be evaluated. The rest of the procedure is, in effect, a process of simple elimination.

The following step-by-step procedure should be used:

1. Spread the sample on a flat surface or in the palm of the hand to aid in observing the relative amounts of coarse and fine-grained components. Classify the soil as coarse-grained

Table 1-5.--The Unified Soil Classification, Laboratory Criteria

						UNIFIED SOIL CLASSES
COARSE-GRAINED SOILS Less than half of material passes the No. 200 sieve size.	GRAVELS Less than half of the coarse fraction passes the No. 4 sieve size.	CLEAN GRAVELS Less than 5% passing the No. 200 sieve size.	Borderline cases require the use of dual symbols.	WELL GRADED Meets gradation requirements	GRADATION REQUIREMENTS ARE: $C_u = \frac{D_{60}}{D_{10}} > 4$ and, $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ < between 1 & 3	GW
				POORLY GRADED Does not meet gradation requirements		GP
		GRAVELS WITH FINES More than 12% passing the No. 200 sieve size.		Plasticity limits of material passing No. 40 sieve size plots below "A" line and P.I. less than 4.	Plasticity limits above "A" line with P.I. between 4 and 7 are border-line cases and require use of dual symbols	GM
				Plasticity limits of material passing No. 40 sieve size plots above "A" line or P.I. more than 7.		GC
	SANDS More than half of the coarse fraction passes the No. 4 sieve size.	CLEAN SANDS Less than 5% passing the No. 200 sieve size.	Borderline cases require the use of dual symbols.	WELL GRADED Meets gradation requirements	GRADATION REQUIREMENTS ARE: $C_u = \frac{D_{60}}{D_{10}} > 6$ and, $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ < between 1 & 3	SW
				POORLY GRADED Does not meet gradation requirements		SP
		SANDS WITH FINES More than 12% passing the No. 200 sieve size.		Plasticity limits of material passing No. 40 sieve size plots below "A" line and P.I. less than 4.	Plasticity limits above "A" line with P.I. between 4 and 7 are border-line cases and require use of dual symbols	SM
				Plasticity limits of material passing No. 40 sieve size plots above "A" line or P.I. more than 7.		SC
FINE-GRAINED SOILS More than half of material passes the No. 200 sieve size.	SILTS AND CLAYS Liquid limit less than 50	Below "A" line and P.I. less than 4		Above "A" line with P.I. between 4 and 7 are border-line cases requiring use of dual symbols		ML
		Above "A" line or P.I. more than 7				CL
		Below "A" line and P.I. less than 4 and $\frac{\text{L.L.(oven dry soil)}}{\text{L.L.(air dry soil)}} < 0.7$		PLASTICITY CHART		OL
	SILTS AND CLAYS Liquid limit greater than 50	Below "A" line				MH
		Above "A" line				CH
		Below "A" line and $\frac{\text{L.L.(oven dry soil)}}{\text{L.L.(air dry soil)}} < 0.7$				OH
HIGHLY ORGANIC SOILS				$\frac{\text{L.L. (oven dry soil)}}{\text{L.L. (air dry soil)}} < 0.7$		Pt

PLASTICITY CHART

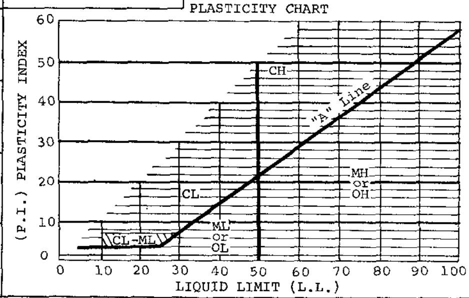

Table 1-6.--Unified Soil Classification, Field Identification

							UNIFIED SOIL CLASSES
COARSE GRAINED SOILS	More than half of material (by weight) is of individual grains visible to the naked eye.	No. 200 sieve size is about the smallest particle visible to the naked eye.	GRAVEL AND GRAVELLY SOILS	More than half of Coarse Fraction (by weight) is larger than ¼ in. size.	For visual classification the ¼ in. size may be used as equivalent to the No. 4 sieve size.	CLEAN GRAVELS Will not leave a dirt stain on a wet palm.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.	GW
							Predominantly one size or a range of sizes with some intermediate sizes missing.	GP
						DIRTY GRAVELS Will leave a dirt stain on a wet palm.	Nonplastic fines or fines with low plasticity (for identification of fines see characteristics of ML below).	GM
							Plastic fines (for identification of fines see characteristics of CL below).	GC
			SAND AND SANDY SOILS	More than half of Coarse Fraction (by weight) is smaller than ¼ in. size.		CLEAN SANDS Will not leave a dirt stain on a wet palm.	Wide range in grain size and substantial amounts of all intermediate particle sizes.	SW
							Predominantly one size or a range of sizes with some intermediate sizes missing.	SP
						DIRTY SANDS Will leave a dirt stain on a wet palm.	Nonplastic fines or fines with low plasticity (for identification of fines see characteristics of ML below).	SM
							Plastic fines (for identification of fines see characteristics of CL below).	SC

					ODOR	DRY CRUSHING STRENGTH	DILATANCY (SHAKE) REACTION	TOUGHNESS	RIBBON (NEAR THE P.L.)	SHINE (NEAR THE P.L.)	UNIFIED SOIL CLASSES
FINE GRAINED SOILS	More than half of material (by weight) is of individual grains not visible to the naked eye.	No. 200 sieve size is about the smallest particle visible to the naked eye.	SILTS AND CLAYS (Low Plastic)	See Identification Procedures		Slight	Rapid	Low to None	None	Dull	ML
						High	Medium to None	Medium	Weak	Slight to Shiny	CL
					Pro-nounced	Medium	Slow to None	Low	None	Dull to Slight	OL
			SILTS AND CLAYS (Highly Plastic)			Medium	Very Slow to None	Medium	Weak	Slight	MH
						Very High	None	High	Strong	Shiny	CH
					Pro-nounced	High	None	Low to Medium	Weak	Dull to Slight	OH
HIGHLY ORGANIC SOILS					Readily identified by color, odor, spongy feel and frequently by fibrous texture.						Pt

Table 1-7.--Unified Soil Classification, Field Identification Procedures

<table>
<tr><th>FIELD IDENTIFICATION PROCEDURES
FOR FINE-GRAINED SOILS OR FRACTIONS</th><th colspan="2">INFORMATION REQUIRED DURING LOGGING</th><th>UNIFIED SOIL CLASSES</th></tr>
<tr><td rowspan="15">These procedures are to be performed on the minus No. 40 sieve size particles, approximately 1/64 in. For field classification purposes, screening is not intended, simply remove by hand the coarse particles that interfere with the tests.

Dry Strength (Crushing characteristics)

After removing particles larger than No. 40 sieve size, mold a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun, or air drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.
High dry strength is characteristic for clays of the CH group. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.
Calcium carbonate or iron oxides may cause higher dry strength in dried material. If acid causes a fizzing reaction, calcium carbonate is present.

Dilatancy (Reaction to shaking)

After removing particles larger than No. 40 sieve size, prepare a pat of moist soil with a volume of about one-half cubic inch. Add enough water if necessary to make the soil soft but not sticky.
Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens, and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.
Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.

Toughness (Consistency near plastic limit)

After removing particles larger than No. 40 sieve size, a specimen of soil about one-half inch cube in size, is molded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms, into a thread about one-eighth inch in diameter. The thread is then folded and rerolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached.
After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles.
The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays which occur below the A-line.
Highly organic clays have a very weak and spongy feel at the plastic limit.
Non-plastic soils cannot be rolled into a thread at any moisture content.
The toughness increases with the P.I.</td><td rowspan="8">COARSE
GRAINED
SOILS</td><td rowspan="8">For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics.

Give typical name; indicate approximate percentages of sand and gravel, maximum size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses.

Example:
<u>Silty sand</u>, gravelly; about 20% hard, angular gravel particles ½ in. maximum size; rounded and subangular sand grains coarse to fine; about 15% nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM).</td><td>GW</td></tr>
<tr><td>GP</td></tr>
<tr><td>GM</td></tr>
<tr><td>GC</td></tr>
<tr><td>SW</td></tr>
<tr><td>SP</td></tr>
<tr><td>SM</td></tr>
<tr><td>SC</td></tr>
<tr><td rowspan="6">FINE
GRAINED
SOILS</td><td rowspan="7">Give typical name, indicate degree and character of plasticity, amount and maximum size of coarse grains, color in wet condition, odor if any, local or geologic name, and other pertinent descriptive information; and symbol in parentheses.

For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions.

Example:
<u>Clayey silt</u>, brown, slightly plastic, small percentage of fine sand, numerous vertical root holes, firm and dry in place, loess, (ML).</td><td>ML</td></tr>
<tr><td>CL</td></tr>
<tr><td>OL</td></tr>
<tr><td>MH</td></tr>
<tr><td>CH</td></tr>
<tr><td>OH</td></tr>
<tr><td>ORGANIC
SOILS</td><td>Pt</td></tr>
</table>

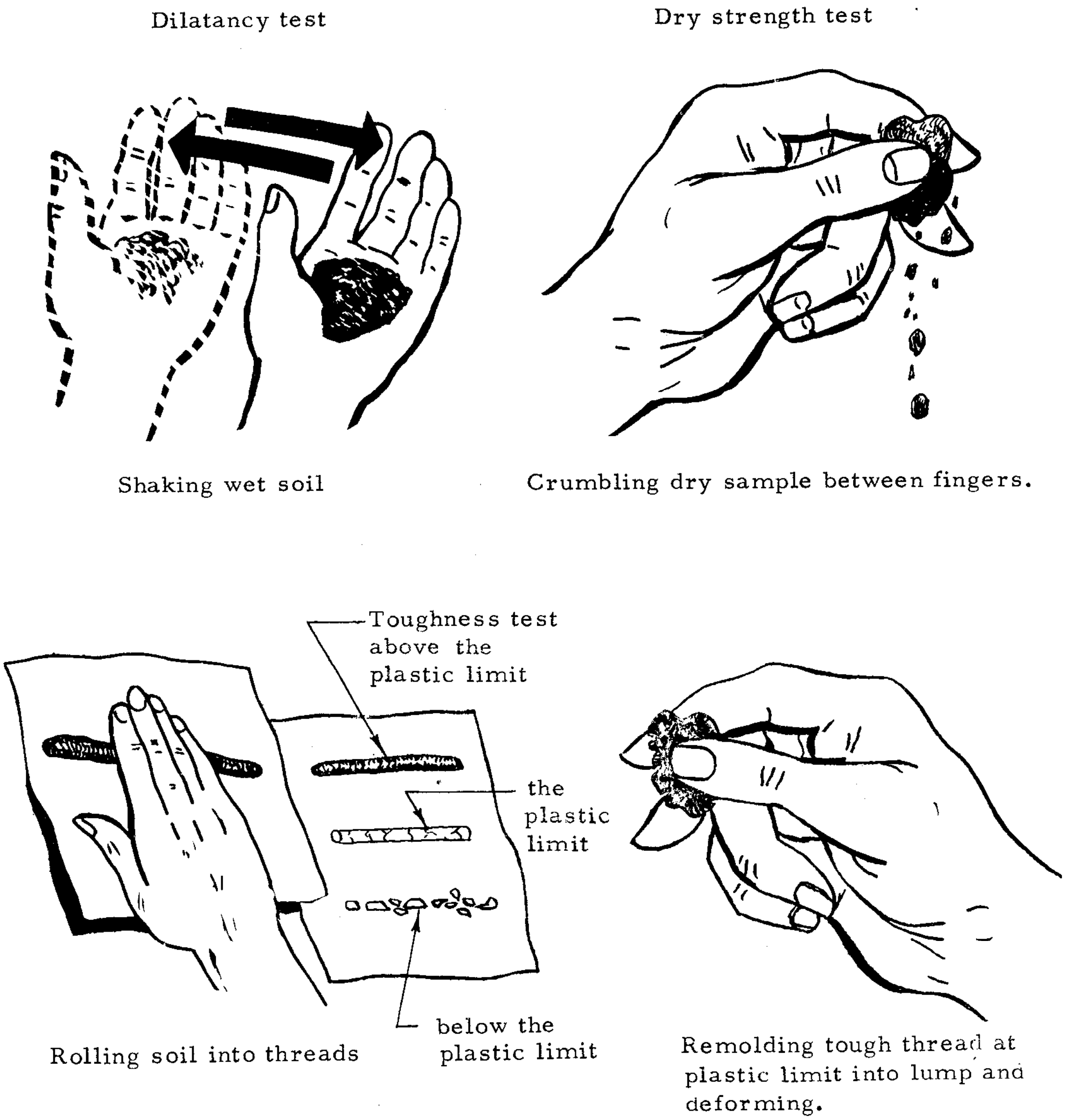

Figure 1-5.--Field Tests

or fine-grained. The division between coarse and fine grain is the 200 mesh sieve.

2. If fine-grained, see step 6 below. If coarse-grained, classify as gravel or sand, i.e., classify as gravel if more than 50 percent of coarse fraction is larger than No. 4 sieve (about 1/4 inch) and sand, if more than 50 percent of coarse fraction is smaller than No. 4 sieve.

3. If gravel or sand, determine whether it is "clean" having less than 5 percent fines; borderline, having 5 to 12 percent fines; or "dirty" having more than 12 percent fines. Fines are defined as the fraction smaller than the 200 mesh sieve size. Less than 5 percent fines will not stain the hands when wet.

4. If the gravel or sand is clean, decide if it is well graded (W) or poorly graded (P) and assign an appropriate group name and symbol: GW, GP, SW, or SP. Well graded materials have a good representation of all particle sizes. Poorly graded materials have an excess or absence of intermediate particle sizes.

5. If the gravel or sand contains more than 12 percent fines, it is classified as GM, GC, SM, or SC, depending upon the type of fines. The procedure for identifying type of fines is given in the following steps: Borderline cases, where fines range from 5 to 12 percent, are classified in the laboratory with dual symbols, i.e., GP-GC, SP-SC. Classification of borderline cases, as well as boundary cases between various groups, require precise laboratory analysis for proper classification. Such analyses cannot be made in the field. When field classification indicates that material might fall into one of two classifications, both symbols should be indicated, such as (GP or GC) or (SW or SP).

6. For fine-grained soils or the fine-grained fraction of a coarse-grained soil, the "dilatancy," "dry strength," and "toughness" tests are performed in accordance with the instructions given on the left-hand side of table 1-7. The group name and symbol are arrived at by selection of that group, the characteristics of which most nearly compare to that of the sample. These characteristics are shown in the lower part of table 1-6.

7. Highly organic soils are classified as peat (Pt). These are identified by color, odor, spongy feel and fibrous texture.

8. Fine-grained soils which have characteristics of two groups, either because of percentage of the coarse-grained components or plasticity characteristics, are given boundary classifications in the same way as coarse-grained soils. Boundary classifications which are common for fine-grained soils are (ML or MH), (CL or CH),

(OL or OH), (CL or ML), (MH or CH). Common boundary classifications between coarse and fine grained soils are (SM or ML) and (SC or CL).

9. Miscellaneous tests and criteria may be used to identify the occurrence of other substances and constituents. Some of these are outlined under Field Tests, pages 1-20 to 1-21.

Table 1-6, Field Identification Criteria, lists in tabular form the classification characteristics of the soil groups. The engineering geologist can only estimate the primary constituents of unconsolidated material in the Unified Soil Classification System. More exact mechanical analyses must be made in the laboratory. However, when the laboratory analyses become available, they should be compared with the original field estimates. In this way the geologist can improve the accuracy of his estimates.

Tables 1-8, 1-9, and 1-10, Engineering Properties of Unified Soil Classes, presents a general evaluation of the engineering properties of the various classes. They provide guidance in determining the suitability of a given soil for various engineering purposes.

Table 1-8.--Engineering Properties of Unified Soil Classes

TYPICAL NAMES	IMPORTANT PROPERTIES						UNIFIED SOIL CLASSES
	SHEAR STRENGTH	COMPRESS-IBILITY	WORKABILITY AS CONSTRUCTION MATERIAL	PERMEABILITY WHEN COMPACTED	K CM. PER SEC.	K FT. PER DAY	
Well graded gravels, gravel-sand mixtures, little or no fines.	Excellent	Negligible	Excellent	Pervious	$K > 10^{-2}$	$K > 30$	GW
Poorly graded gravels, gravel-sand mixtures, little or no fines.	Good	Negligible	Good	Very Pervious	$K > 10^{-2}$	$K > 30$	GP
Silty gravels, gravel-sand-silt mixtures.	Good to Fair	Negligible	Good	Semi-Pervious to Impervious	$K = 10^{-3}$ to 10^{-6}	$K = 3$ to 3×10^{-3}	GM
Clayey gravels, gravel-sand-clay mixtures.	Good	Very Low	Good	Impervious	$K = 10^{-6}$ to 10^{-8}	$K = 3 \times 10^{-3}$ to 3×10^{-5}	GC
Well graded sands, gravelly sands, little or no fines.	Excellent	Negligible	Excellent	Pervious	$K > 10^{-3}$	$K > 3$	SW
Poorly graded sands, gravelly sands, little or no fines.	Good	Very Low	Fair	Pervious	$K > 10^{-3}$	$K > 3$	SP
Silty sands, sand-silt mixtures.	Good to Fair	Low	Fair	Semi-Pervious to Impervious	$K = 10^{-3}$ to 10^{-6}	$K = 3$ to 3×10^{-3}	SM
Clayey sands, sand-clay mixtures.	Good to Fair	Low	Good	Impervious	$K = 10^{-6}$ to 10^{-8}	$K = 3 \times 10^{-3}$ to 3×10^{-5}	SC
Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	Fair	Medium to High	Fair	Semi-Pervious to Impervious	$K = 10^{-3}$ to 10^{-6}	$K = 3$ to 3×10^{-3}	ML
Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Fair	Medium	Good to Fair	Impervious	$K = 10^{-6}$ to 10^{-8}	$K = 3 \times 10^{-3}$ to 3×10^{-5}	CL
Organic silts and organic silty clays of low plasticity.	Poor	Medium	Fair	Semi-Pervious to Impervious	$K = 10^{-4}$ to 10^{-6}	$K = 3 \times 10^{-1}$ to 3×10^{-3}	OL
Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Fair to Poor	High	Poor	Semi-Pervious to Impervious	$K = 10^{-4}$ to 10^{-6}	$K = 3 \times 10^{-1}$ to 3×10^{-3}	MH
Inorganic clays of high plasticity, fat clays.	Poor	High to Very High	Poor	Impervious	$K = 10^{-6}$ to 10^{-8}	$K = 3 \times 10^{-3}$ to 3×10^{-5}	CH
Organic clays of medium to high plasticity, organic silts.	Poor	High	Poor	Impervious	$K = 10^{-6}$ to 10^{-8}	$K = 3 \times 10^{-3}$ to 3×10^{-5}	OH
Peat and other highly organic soils.	NOT SUITABLE FOR CONSTRUCTION						Pt

Table 1-9.--Engineering Properties of Unified Soil Classes for Embankments

EMBANKMENTS								
COMPACTION CHARACTER-ISTICS	STANDARD PROCTER UNIT DENSITY LBS. PER CU. FT.	TYPE OF ROLLER DESIRABLE	RELATIVE CHARACTERISTICS PERME-ABILITY	RELATIVE CHARACTERISTICS COMPRESS-IBILITY	RESISTANCE TO PIPING	ABILITY TO TAKE PLASTIC DEFORMATION UNDER LOAD WITHOUT SHEARING	GENERAL DESCRIPTION & USE	UNIFIED SOIL CLASSES
Good	125-135	crawler tractor or steel wheeled & vibratory	High	Very Slight	Good	None	Very stable, pervious shells of dikes and dams.	GW
Good	115-125	crawler tractor or steel wheeled & vibratory	High	Very Slight	Good	None	Reasonably stable, pervious shells of dikes and dams.	GP
Good with close control	120-135	rubber-tired or sheepsfoot	Medium	Slight	Poor	Poor	Reasonably stable, not well suited to shells but may be used for impervious cores or blankets.	GM
Good	115-130	sheepsfoot or rubber-tired	Low	Slight	Good	Fair	Fairly stable, may be used for impervious core.	GC
Good	110-130	crawler tractor & vibratory or steel wheeled	High	Very Slight	Fair	None	Very stable, pervious sections, slope protection required.	SW
Good	100-120	crawler tractor & vibratory or steel wheeled	High	Very Slight	Fair to Poor	None	Reasonably stable, may be used in dike with flat slopes.	SP
Good with close control	110-125	rubber-tired or sheepsfoot	Medium	Slight	Poor to Very Poor	Poor	Fairly stable, not well suited to shells, but may be used for impervious cores or dikes.	SM
Good	105-125	sheepsfoot or rubber-tired	Low	Slight	Good	Fair	Fairly stable, use for impervious core for flood control structures.	SC
Good to Poor Close control essential	95-120	sheepsfoot	Medium	Medium	Poor to Very Poor	*Very Poor	Poor stability, may be used for embankments with proper control. *Varies with water content.	ML
Fair to Good	95-120	sheepsfoot	Low	Medium	Good to Fair	Good to Poor	Stable, impervious cores and blankets.	CL
Fair to Poor	80-100	sheepsfoot	Medium to Low	Medium to High	Good to Poor	Fair	Not suitable for embankments.	OL
Poor to Very Poor	70-95	sheepsfoot	Medium to Low	Very High	Good to Poor	Good	Poor stability, core of hydraulic fill dam, not desirable in rolled fill construction.	MH
Fair to Poor	75-105	sheepsfoot	Low	High	Excellent	Excellent	Fair stability with flat slopes, thin cores, blanket & dike sections.	CH
Poor to Very Poor	65-100	sheepsfoot	Medium to Low	Very High	Good to Poor	Good	Not suitable for embankments.	OH
DO NOT USE FOR EMBANKMENT CONSTRUCTION								Pt

Table 1-10.--Engineering Properties of Unified Soil Classes for Foundations and Channels

CHANNELS: LONG DURATION TO CONSTANT FLOWS.		FOUNDATION: FOUNDATION SOILS, BEING UNDISTURBED, ARE INFLUENCED TO A GREAT DEGREE BY THEIR GEOLOGIC ORIGIN. JUDGEMENT AND TESTING MUST BE USED IN ADDITION TO THESE GENERALIZATIONS.					
RELATIVE DESIRABILITY			RELATIVE DESIRABILITY		REQUIREMENTS FOR SEEPAGE CONTROL		
EROSION RESISTANCE	COMPACTED EARTH LINING	BEARING VALUE	SEEPAGE IMPORTANT	SEEPAGE NOT IMPORTANT	PERMANENT RESERVOIR	FLOODWATER RETARDING	UNIFIED SOIL CLASSES
1	-	Good	-	1	Positive cutoff or blanket	Control only within volume acceptable plus pressure relief if required.	**GW**
2	-	Good	-	3	Positive cutoff or blanket	Control only within volume acceptable plus pressure relief if required.	**GP**
4	4	Good	2	4	Core trench to none	None	**GM**
3	1	Good	1	6	None	None	**GC**
6	-	Good	-	2	Positive cutoff or upstream blanket & toe drains or wells.	Control only within volume acceptable plus pressure relief if required.	**SW**
7 if gravelly	-	Good to Poor depending upon density	-	5	Positive cutoff or upstream blanket & toe drains or wells.	Control only within volume acceptable plus pressure relief if required	**SP**
8 if gravelly	5 erosion critical	Good to Poor depending upon density	4	7	Upstream blanket & toe drains or wells	Sufficient control to prevent dangerous seepage piping.	**SM**
5	2	Good to Poor	3	8	None	None	**SC**
-	6 erosion critical	Very Poor, susceptible to liquefication	6, if saturated or pre-wetted	9	Positive cutoff or upstream blanket & toe drains or wells.	Sufficient control to prevent dangerous seepage piping.	**ML**
9	3	Good to Poor	5	10	None	None	**CL**
-	7 erosion critical	Fair to Poor, may have excessive settlement	7	11	None	None	**OL**
-	-	Poor	8	12	None	None	**MH**
10	8 volume change critical	Fair to Poor	9	13	None	None	**CH**
-	-	Very Poor	10	14	None	None	**OH**
-	-	REMOVE FROM FOUNDATION					**Pt**

No. 1 is best numerical rating.

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